Principal Components Analysis of Reflectance Spectra From the Mars Exploration Rover Opportunity

C. M. Mercer, Middlebury College, and B. A. Cohen, Marshall Space Flight Center

Introduction

• In the summer of 2007 a global dust storm on Mars effectively disabled Opportunity's Miniature Thermal Emission Spectrometer (Mini-TES), the primary instrument used by the Athena Science Team to remotely identify locally unique rocks on the Martian surface.

• The science team needs another way to distinguish interesting rocks from their surroundings on a tactical timescale. This study was designed to develop the ability to identify locally unique rocks on the Martian surface remotely using the Mars Exploration Rovers' Panoramica Camera (Pancam) instrument.

• Meridiani bedrock observed by Opportunity is largely characterized by sulfate-rich sandstones and hematite spherules. Additionally, loose fragments of bedrock and "cobbles" of foreign origin collect on the surface, some of which are interpreted as meteorites.

Methodology

• The Pancam Instrument:
  - High resolution, stereoscopic, panoramic camera
  - 13 filters cover 11 VNIR wavelengths (432-1009 nm)

• Database:
  - 310 reflectance spectra extracted from Pancam 13-Filter (13F) images: 70 spectra of bedrock, and 240 spectra of cobbles, including Barberton, Heat Shield Rock, Santa Catarina, Jin, Bounce Rock, and Arkansas
  - 10 RELAB mineral spectra including: clinopyroxene, orthopyroxene, forsterite, fayalite, hematite, magnetite, and goethite

• Spectral Parameters:
  - 16 spectral parameters for each rock spectrum (Table 1)
  - Each spectral parameter represents physical characteristics of the rock, e.g. degree of oxidation, mineralogical composition, and albedo

• Principal Components Analysis (PCA):
  - Output components are linear combinations of spectral parameters
  - Allows us to identify which physical characteristics of the targeted rocks contribute most to the overall variability of the dataset

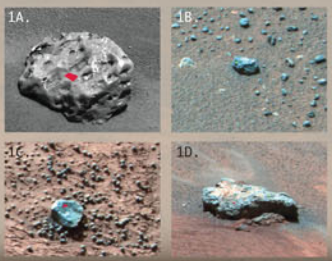


Figure 1: Some of the named rocks and cobbles included in our database. Areas where spectra were extracted are indicated by colored regions. 1A) The meteorite "Heat Shield Rock," seen on Sol 346, P2591. 1B) Exotic cobble "Arkansas," seen on Sol 550, P2579. 1C) The meteorite "Barberton," seen on Sol 123, P2535. 1D) Exotic rock "Bounce Rock," seen on Sol 63, P2570.

Table 1. Spectral parameters used in this study.

ID	Parameter	ID	Parameter
1	432 to 601 "blue" slope	9	535 nm band depth
2	436 to 754 slope	10	601 nm band depth
3	482 to 535 slope	11	904 nm band depth
4	535 to 601 slope	12	535 spectral inflection
5	754 to 864 slope	13	803/904 ratio
6	754 to 1009 slope	14	934/1009 ratio
7	864 to 934 slope	15	753/432 "L2/L7" ratio
8	934 to 1009 slope	16	Maximum R* value

Results of PCA

• Including all 16 parameters in PCA, we found that parameter 15 constitutes 89% of the first component and accounts for 88% of the overall variance of the dataset (Table 2)
  - This parameter has been used to measure the degree of oxidation of bedrock at Meridiani Planum (Farrand et al., 2007), and may relate to variations in the level of oxidation of cobbles
  - Could also be affected by dust coatings and/or concentration of hematite (shadowed spectra were excluded from our database)

• Excluding parameter 15 from PCA, we found that parameters 9, 11, 13, 14, and 16 are the dominant constituents of the first five components, and account for much of the remaining variability (Table 3). They could indicate:
  - Trends in oxidation or dust contamination (parameter 9)
  - Generic type or crystallinity of ferric minerals (parameters 9, 11, 13, and 14)
  - Trends in albedo (e.g. parameter 16)

• Parameters 1-8 are negligible contributors to the variance of the dataset

Table 2: Scaled Coefficients (as percents) of Selected parameters
Note: all parameters included in PCA in this analysis

Parameters:	9	11	13	14	15	16	% Variance
Component 1	4.5	0.9	0.7	1.4	88.8	2.0	99.2
Component 2	0.7	25.1	24.8	29.4	1.2	16.2	0.3
Component 3	2.6	9.7	27.5	5.5	0.8	47.4	0.2
Component 4	34.6	2.9	19.2	21.2	1.9	14.7	0.2
Component 5	33.0	0.5	21.5	25.8	1.6	13.6	0.1

Table 3: Scaled Coefficients (as percents) of Selected parameters
Note: parameter 15 excluded from PCA in this analysis

Parameters:	9	11	13	14	16	% Variance
Component 1	30.2	12.0	12.6	14.5	20.4	46.8
Component 2	25.3	20.9	17.2	26.4	2.4	23.8
Component 3	15.5	6.3	27.6	11.8	34.4	17.0
Component 4	12.9	1.1	26.1	27.5	25.1	8.9
Component 5	12.3	1.7	8.2	6.2	3.0	3.2

Analysis

• We plotted output components in ternary diagrams, exploring what combinations would produce recognizable trends to differentiate between rock types.

• A plot of the first three components shows that most rocks plot near the vertex for component 1
  - Because parameter 15 dominates the principal component, points nearer to the vertex of component 1 may represent rocks with a higher degree of oxidation
  - Where available, data collected by Opportunity's Mössbauer spectrometer (MB) and Alpha Particle X-ray Spectrometer (APXS) should be used to better characterize these outliers and to better understand the meaning of parameter 15

• When parameter 15 is excluded from PCA, the rocks spread out more evenly among the first three components
  - Points representing bedrock, known meteorites, RELAB mineral spectra, and cobbles do not plot within distinct fields
  - The mathematical technique of Hierarchical Clustering may help to define statistically significant clusters within the dataset

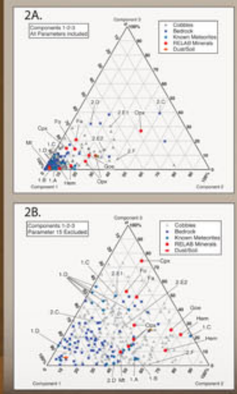
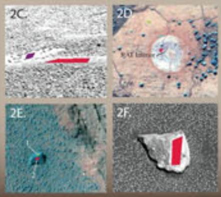


Figure 2: Ternary diagrams of output data. 2A) Components 1, 2, and 3 output by PCA with all 16 parameters included. 2B) Components 1, 2, and 3 output by PCA excluding parameter 15; note that different rock types do not plot in distinct fields. 2C-F) Outliers labeled in plot A: 2C) Purple region: exposed bedrock seen on Sol 32, P2583; 2D) Red region: RAT interior of "Berry Bowl," Sol 48, P2568; 2E) (1) Green region: cobble upper surface, and (2) red region: cobble surface, seen on Sol 929, P2376; 2F) Cobble seen on Sol 1150, P2536.



Conclusions

Much progress has been made in developing the ability to remotely identify rocks of interest at Meridiani Planum using Opportunity's Pancam. We found that parameters 1-8 are negligible contributors to the variability of the dataset, and may be excluded. With continued research utilizing MB and APXS data gathered by Opportunity, and additional analytical techniques, this methodology may be expanded upon to regain capabilities to remotely identify locally unique rocks on a tactical timescale.

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Cameron Mercer -- Middlebury College, Middlebury, VT
e-mail: cmercer@middlebury.edu
Barbara Cohen -- NASA Marshall Space Flight Center, VP62
e-mail: barbara.a.cohen@nasa.gov